REVIEW OF CHEMICAL CONTROL
OF DAMPING-OFF
IN FOREST NURSERIES

by

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CONTENT

PREFACE

Chemical control of damping-off diseases has long been a subject of many investigations. The number of papers dealing with this problem is increasing at a high rate. This fact itself indicates the seriousness of the problem. It seems that no universally effective control measures have yet been found, but the methods tried are improving. Certain methods that are adequate at one time may fail at other times. Generally speaking, the results obtained are inconsistent. Mostly the causes of the variation in results are not known. This is not surprising since the basic knowledge about the ecology of this group of diseases is very scarce and the mode of action of most of the chemicals has not been discovered. In several publications, especially in short abstracts, there are no details about environment, causal organisms, phytotoxicity, controls, or replications. These details may have been completely neglected or not published. Very commonly only one dosage of each fungicide has been applied. Yet there has been no assurance that the dosage (usually that generally recommended by the manufacturer) was really sufficient or not too large under the particular conditions.

In the following review an attempt is made to find the most promising modern trends in chemical control of damping-off rather than to survey completely the history of this. Horsfall's book (1945) is recommended for students who are more interested in the history and chemistry of fungicides.

The inconsistency of results, basic ignorance about the modifying factors, and insufficient design or presentation make it very difficult to review this literature in a brief form. It is impossible here to refer to a large proportion of all the pertinent studies, or to include many details. Because of these difficulties, this review does not pretend to be free of subjectivity. Some important studies or details may have been ignored. The author's intention is to add continuously new references to this review. The author would be grateful if any of the readers would send additions or comments.

The names of the chemicals referred to and their synonyms appear in the appendix.

The specific purpose of this review is to serve as a basis for evaluating the possible methods of controlling the serious damping-off of conifers and caragana in Saskatchewan and Manitoba. These diseases are caused mainly by Rhizoctonia solani, Pythium spp. and Fusarium spp. which are also known to be the most important damping-off pathogens of wide distribution on many plant species. Although damping-off refers rather to symptoms or to a name of diverse diseases, the damping-off problem is universal and in many respects similar in widely separated places and on various plants. Thus the investigations on other than forest plants were considered suggestive and are frequently referred to. Accordingly this review may be useful to others than foresters in the Prairie Provinces.

INTRODUCTION

DO[1] is caused mainly by pathogenic organisms. Physiological DO (Beach 1949) is of relatively minor importance if proper watering and light are provided to seedbeds. Pathogenic DO can be controlled by breeding for resistance to the pathogens, by changing environment to disfavour infection, or by internal chemotherapy.

Although many DO pathogens are very virulent and little specialized, the following findings, for instance, suggest a possibility of controlling DO by breeding: Some races of safflower are resistant to Phytophtora (Thomas 1952) and Pythium (Cormack and Harper 1953). Barley varieties differ greatly in their susceptibility to Pythium (Bruehl 1952). Certain green strains of pea are significantly more resistant to DO caused by Pythium or Rhizoctonia than yellow strains (McCallum 1948).

The change in environment for controlling DO may be mainly biological, physical, or chemical. Since Weindling made his discovery about the antagonism of Trichoderma to Rhizoctonia, the biological control of DO has been an attractive possibility (Weindling and Hawcett 1936, Krasilnikov and Ratznitsina 1946,

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[1] Abbreviation for "damping off"

Newhook 1951, Wood 1951, Gregory et al 1952 a and b, etc.). Weindling (1946) himself states, however, that no universal means exist and much research is needed before biological control of DO and related diseases is commonly practicable.

Perhaps the most promising method in this field is the pelleting of seed with a mixture of cellulose, nutrients and an antagonist. Gregory et al (1952 b) provided temporary protection to alfalfa from Pythium DO by this means using species of Trichoderma and Penicillium as antagonists. The protection did not last enough to protect at high temperatures.

When antibiotics or acidifying materials are applied, the biological, chemical, and the physical control overlap each other. Even the ordinary chemical control measures, such as application of thiram to soil, not only suppress the microorganisms in general but also change biological equilibrium. This effect may be considered as approaching biological control of DO (see references later).

Of the physical control measures, the favourable effect of light (Tint 1945, Vaartaja 1952) is an example. The direct use of light may be practical in greenhouses (Tiedjens 1929).

The most promising means of controlling DO is by industrial chemicals, new forms of which are being developed at an increasing rate. Theoretically, DO should be controllable by chemicals. It is only necessary to introduce to the plant-pathogen complex or to either of them sufficient chemical that is harmless to the plant but inhibits the pathogen directly or indirectly. This should be quite possible since the physiology of DO pathogens differs widely from that of the plant. In human chemotherapy this principle has often been applied successfully since the invention of penicillin.

In the following, the chemical control of DO is reviewed by classifying the methods according to the way in which the chemicals are applied or act biologically. The classes are not quite logically defined but are naturally developed during the short history of pesticides.

SEED TREATMENT BY FUNGICIDES

Treating cereal seed, mostly by mercury compounds, has long been a common practice (Leukel 1948). This is mainly against important seed-borne diseases. The treatment is not effective against fungus attacks long after germination. According to Vanterpool (1952), seed treatments do not directly protect cereals from Pythium root rot, but only indirectly, due to the increased vigor of seedlings. Besides mercury compounds, various others (chloronitrobenzenes, NP-1083, Vancide 51 etc., Holton and Woo 1953) have shown promise for seed of certain cereals.

Though there are indications (Fisher 1941, Rathbun-Gravatt 1931) that some DO of conifers is spread via seed, by far the most important DO types of trees are soil-borne. The common pathogens include such soil fungi as species of Phytophtora, Pythium, Rhizoctonia, Sclerotium, and Fusarium (Hartley 1921, Wiant 1929, Roth 1935, Lambart and Crandall 1936, Jackson 1940, Ten Houten 1939, Wright 1944, Tint 1945, Riker et al 1946, Carrera 1951, etc.) and sometimes soil nematodes (Wilde 1936, Henry 1953.

The attempts to control DO of trees by ordinary seed treatments have given variable results (Davis et al 1941, Baldwin 1942, Carlson 1946, Riker 1947, Doran 1947, Hamilton and Jackson 1951, Strong 1952). In some cases chemical injury has been responsible for the unsatisfactory results. According to Hartley (1950), most DO of trees occurs too long after germination to be affected by seed treatment.

In Strong's (1952) tests in Michigan with 24 chemicals, only Orthocide (captan) gave really good and lasting protection for Scots pine, red pine, Douglas fir and Norway spruce in soils containing Rhizoctonia, Fusarium, and Pythium naturally. A few of the chemicals, however, reduced the losses somewhat, namely, copper carbonate, Crag 658, and Phygon. Besides these, the following fungicides evidently exerted a protection of short duration by considerably increasing emergence over the control: 640, 5400, Agrox, Bioquin I, Vancide 51, and Tersan. Spergon, Fermate, Semesan, N. I. Ceresan, and Puraturf 177 gave some protection from postemergence DO but reduced emergence. This is probably an indication of chemical injury to germinating seed.

The success of seed treatment for various garden crops and forage legumes has also varied. Many generally good results are obtained, e.g., to peanuts, peas, beans and some other leguminous plants, mostly by the use of quinones (Phygon, Spergon), and more recently, of Vancide 51, captan, or dithiocarbamates (Arasan and others) (Baylis et al 1943, Johnson 1948 and 1951, Doran et al 1942, Tisdale et al 1945, McCallan 1946, 1948 and 1950, Vlitos and Preston 1949, Wilson 1949, Kernkamp 1950, Kreitlow et al 1950, Sherf and Reddy 1952, Harrison et al 1953, Johnson et Kilpatrick 1953, Mead 1953, Fulkerson 1953). On the other hand, seed treatment has often given insufficient control for postemergence DO (Kadow and Anderson 1937, McCallan 1948, McKeen 1950, Hanson 1952). When conditions are particularly favourable to DO, seed treatment may fail to control even preemergence DO (Kadow and Anderson 1937, Tisdale et al 1945, McKeen 1950, Linnasalmi 1952).

The failure of seed treatments is sometimes due to the presence of unusually virulent strains of pathogens. This was the case in the tests of Weber (1952) for controlling <u>Rhizoctonia</u> and <u>Collectotrichum</u> DO of alfalfa by the use of Arasan, Phygon, or Spergon.

Kadow and Anderson (1937) reported that certain fungicides sometimes adhered well to seed but failed at other times. There are also indications (McKeen 1950) that the success of a treatment depends on the size of the seed. Small seeds (e.g. alfalfa and clover, Hanson 1952) cannot carry a large enough quantity of chemical to affect materially the pathogens around the seed. This hypothesis is supported by results of tests where larger amounts of chemical were applied to small seeds by means of the sticker, methyl cellulose. Berbee et al (1953) pelleted red pine seed in this way and obtained very good control of Rhizoctonia DO. Thiram at 12.5% of seed weight gave good control with double the quantity of 4% methyl cellulose as a sticker. Besides serving as a reservoir for the fungicide, methyl cellulose around the seed perhaps also protected the seed from too intensive chemical effects. With the cellulose, pine seeds tolerated even the doses of 400% thiram. This method of protection of seed from both chemical injury and pathogens is illustrated by the study of Andersen (1952) with beans. Colletotrichum infection was completely controlled only by treating the seed with the slurry of about 10% Vancide 51 and 3% cellulose. Several other methods and chemicals tested were ineffective or injurious. On the other hand, cellulose (or water) slurry with Ceresan M has been more injurious to certain pea varieties than the dry chemical; these varieties were particularly sensitive to chemical injury (de Zeeuw and Anderson 1952). In other cases no marked chemical injury has resulted to pea from Arasan, Spergon, or Phygon with or without cellulose (de Zeeuw and Anderson 1952, Hagedorn 1953). The results of Larson and Walker (1953) suggest that the cellulose pelleting decreases the effectiveness of thiram (against onion smut fungus) a little.

Because of the inconsistency in DO control by ordinary seed treatments, more thorough review of the pertinent investigations will not be presented. It could include hundreds of references; even so early a bibliography as that of Kadow and Anderson (1937) already mentions one hundred and sixteen investigations mainly about seed treatments.

SOIL ACIDIFYING

Compounds that increase soil acidity have long been the most important chemicals (besides formaldehyde) for reducing Rhizoctonia and Pythium DO of conifers. Hartley, who himself is a pioneer in this field (1915, 1917) has recently reviewed (1950) the use of these chemicals. The most successful and widely used ones are sulphuric acid, aluminum sulphate, phosphoric acid, and ferrous sulphate.

The mode of action of acid treatments is not well understood but seems to be only partly fungicidal. Acids may increase the resistance of the hosts (Jackson 1940) and increase the antagonism by other soil organisms, (Weindling 1936, Katznelson and Richardson 1948); they may thus exhibit chemoterapeutic and biological control. Some acids are also fungicides, e.g. salisylic acid, that possess effective fungicidal properties especially towards Pythium (Carrera 1951). However, this acid is somewhat toxic to the plants (Linnasalmi 1952) as are many other acids.

Acidifying chemicals often harm the soil (Hartley 1921, Riker 1947) and fail in control (Hartley 1917, Riker 1947), Strong 1952). In Wilner's tests (personal communication) at Indian Head, Saskatchewan, acidifying chemicals gave inconsistent control to DO of Scots pine.

STERILIZATION OF SOIL

Soil-borne pathogens may be controlled by such physical agencies as heat, or chemically by volatile poisons. Formaldehyde is the best known of the latter group.

This type of chemical control can be very effective, but has three serious handicaps (Kadow and Anderson 1937, Doran et al 1942, Linnasalmi 1952 etc.): (1) It must be done very thoroughly and the treatment must include all of the soil in the pot or flat, or relatively large areas in the field; this is expensive. (2) Reinfestations may frustrate the whole effort. DO due to reinfestations is often worse than without any treatments at all because of the decreased antagonism. (3) Difficulties in handling the chemicals and dangers of poisoning to humans. Despite the disadvantages, chemical sterilization of the soil is commonly used especially in greenhouses (Doran et al 1942).

Soil sterilization has been found to improve the growth of plants in addition to decreasing the rate of DO. The effect is due, at least in some instances, simply to the eradication of disease organisms that otherwise would cause slight infection and thus retard growth of the plants (Doran et al 1942). The same effect has been found from the use of some other types of fungicides (of thiram, Riker et al 1947).

Formaldehyde has been used long in some conifer nurseries, especially where acidifying chemicals have proved deleterious to soil (Hartley 1950). Cox (1953) found chlorpicrin gas to be equally effective. In some nurseries the injection of ethylenedibromide into soil is practiced (Henry 1953). This eradicated also the nematodes that together with fungi caused serious root injury to southern pines.

A new method combining soil sterilization and biological control is under development (Warcup 1951). Soil is sterilized one or more months before seeding, usually by formaldehyde. The sterile or nearly sterile soil meanwhile becomes colonized by saprophytes. These are assumed to be effectively antagonistic to DO pathogens.

SOIL TREATMENT BY PERSISTENT FUNGICIDES

These chemicals differ from those of the previous group in being not very volatile but persisting and acting in soil for a longer period. Their action is more specifically against DO organisms while often lacking in general toxicity.

Semesan has been applied to the soil at the time of seeding to control successfully the DO of various conifers (Wiant 1929, Davis 1941, Johnson and Linton 1942). Wiant (1929) observed chemical injury to several spruce species and larch from this and related compounds. Injuries resulted sometimes even to red pine from post-emergence applications. In Wiant's (1929) experiments, the protecting effect of a single application of Semesan lasted over the most critical DO (Rhizoctonia) period. Semesan seems to be (Linnasalmi 1952) one of the least phytotoxic of the mercury compounds. Some new ones of this group, for instance, ethylmercuric perthio-cyanate (Hagedorn 1952, Heuberger 1952), may also be only slightly phytotoxic.

Horsfall (Linnasalmi 1952) obtained promising results by copper and zinc compounds for conifers and other plants, especially in combined seed and soil treatments, but the dosage effective against Rhizoctonia DO seems to be phytotoxic (Dunlop 1936, Linnasalmi 1952). Davis et al (1941) found that copper oxide is especially injurious to seeds during hot weather.

Doran (1947) reported that soil application of Arasan at 50 lbs. / acre increased the stands of Rhododendron hybrids. Riker et al (1947) reported relatively good control of Pythium and Rhizoctonia DO by a soil application of calomel or thiram at approximately 200 - 500 lbs. / acre, for red pine in Wisconsin. Benzenehexachloride at 1 lb. / acre controlled Rhizoctonia DO of red pine in Wisconsin (Simkover and Shenefelt 1951). Heavier dosages caused root injury.

Recently, good control of red pine DO in Michigan soils containing Rhizoctonia and Pythium was obtained by soil treatments (Strong 1952). The best fungicides amongst a number tested were Tersan, Ceresan M, N. I. Ceresan, Manzate, and the experimental fungicide 5400 at 150 - 300 lbs. / acre.

No protection from post-emergence DO, or even increase in it, resulted from some of the soil treatments (Strong 1952). Since pre-emergence DO was controlled by most of these fungicides, it seems probable that this is a result of reinfestation after the influence of the fungicide had ceased. Puraturf 177, Bioquin I, Vancide 51, Captan, Crag 658, and Agrox were in this group of fungicides.

Thiram (50 lbs. / acre) as well as Vancide 51 in heavy doses (400 lbs. / acre) gave good control in single soil applications (Berbee et al 1953) against Rhizoctonia DO of red pine in Wisconsin. Vancide 51 (10 - 40 lbs. / acre) has also given promising results against DO of red clover and alfalfa (Fulkerson 1953).

Crandall (1950) controlled Rhizoctonia DO of coffee and cinchoma by repeated applications of wettable Spergon to soil and plant. Each of the weekly applications was with plenty of water at the rate of 75 lbs. / acre and was followed by water rinsing.

Increased control of DO was reported by Strong (1952) when the fungicides were applied in three applications instead of one. The applications began a week after seeding with intervals of one week. Good control was obtained this way by Tersan, Manzate, Orthocide (captan), Crag 658, and 5400. Three applications, each at 50 lbs. / acre, was satisfactory. Only slightly better control resulted from 3 x 100 lbs. / acre and 3 x 7 lbs. / acre was insufficient. Monthly irrigations of avocado trees with Dithane D-14 has markedly reduced Phytophtora cinnamomi population (Zentmyer 1952).

The success of repeated applications is interesting because it may offer more certain means of controlling reinfestation until the DO period is over. For this, the chemicals must be of very low phytotoxicity.

Thiram is considered to be less phytotoxic than most earlier fungicides (McCallan 1946, McCallan 1950, Linnasalmi 1952, etc.), although Jacks (1951) reported observations to the contrary. It has been reported to have caused some injury to lettuce, tomato (Jacks 1951), celery (McKeen 1950), and to sugar beet at high (27 - 29°C.) temperatures (Hildebrand et al 1949). The herbicidal effects of thiram in conifer seedbeds (Riker et al 1947, Berbee et al 1952) suggest that this chemical may be tolerated better by conifers than other plant groups.

Thiram, Manzate, and captan are standard fungicides of tomato and fruit growers. This indicates low phytotoxicity of these chemicals. Vaartaja (unpublished) found that these and some other pesticides (N-244, lime sulphur, chinosol, Perenox) did not injure spruce seedlings at the Big River, Saskatchewan, nursery when applied on the foliage in September at 100 lbs. / acre; at 300 lbs. / acre Phygon was slightly injurious while captan was not. All these chemicals were injurious to germinating birch seed, captan being the least toxic (Vaartaja, unpublished). Cotton seeds tolerated the following maximum concentrations of fungicides (Anonymous 1951): Ceresan and Dow 9B - 0.3% (of seed weight); Arasan M, Zerlate, 5400, pentachloronitrobenzene -

3%; Orthocide, Spergon - 5%. Strong (1952) and Siggers (1951) also reported injury to pine seed or foliage from Phygon. Correct doses (0.25 or 0.6%) of Arasan, Fermate, and Phygon increased germination of southern pines while mercury compounds often caused injuries in tests by Hamilton and Jackson (1950).

Spergon, Manzate, chinosol, Ceresan, mercuric chloride solution, thiram, Arasan, Tersan, and Orthocide were toxic to seed of white spruce and caragana in the tests of Cram and Vaartaja (unpublished); the maximum doses adhering to seed were tested before or after stratification. The toxicity of thiram and captan was low.

Ferbab, zineb, thiram, captan (this also in repeated applications), Vancide 51, and Manzate are commonly reported to control DO or blights of various plants when applied to soil and plants (Townsend 1944, Hildebrand et al 1949, Haasis and Ellis 1950, Jacks 1951, Newhall and Gunkel 1951, McKeen 1950, Linnasalmi 1952, Powell 1953, Taylor 1953, Pelletier 1953, Harrison 1953, Beach 1953). No reference was found concerning Caragana, but these fungicides seem to be rather universally effective regardless of the host species.

DO of various plants has been controlled by applying thiram, Phygon, or Manzate to the soil with fertilizers (Hildebrand et al 1949, Doran 1950, Yale 1953). In band or row applications (Hildebrand et al 1949, Newhall and Gunkel 1951), the effective amount of thiram dust has been as low as 20-30, even 3 lbs./acre.

To mention only a few more of numerous new soil fungicides: nitrobenzenes (Tritisan, Folosan and others) are good ones against various DO (Newhook 1951, Linnasalmi 1952 and 1953, Miller 1952, Hooker 1954); trichlorophenyl acetate (Mycotox I) was comparable with Arasan in tests by Hildebrand et al (1949); Zineb (Dithane Z-78) has been the best in some tests for controlling Bremia, Rhizoctonia, and Fusarium DO of lettuce, beans and sugar beet (Haasis and Ellis, 1950, Anonymous 1950, 1951).

Very little is known about the penetration and persistency of fungicides in soil and their action during their decline. Nabam, that is water soluble, breaks down into highly fungicidal insoluble compounds under certain conditions (Ludwig et al 1954).

Only three fungicides (Nabam, Dowicide G, and Vancide 51) out of forty tested remained effective to kill Phytophtora cinnamomi after being filtered through 1 inch of soil from surface application at a dilution of 1:500 (Zentmyer 1952). However, a fungicide (Arasan), may only inhibit a DO fungus (Rhizoctonia) locally in seed rows at or near the soil surface, and still control the disease (Hildebrand et al 1949, McKeen 1950). Actually thiram has given a better control when it was worked into the shallow surface soil along narrow strips at seed rows than when the whole soil was treated (personal communication from McKeen).

Thiram has been found (Richardson and Thorn 1953) to persist in sand for eight weeks but in compost only for four days. After thiram was decomposed, another weaker fungicide was formed. Protection from reinfestation continued partly because of a change in microbial population. According to Manten et al (1950) thiram is more toxic to many pathogenic fungi than to many saprophytic fungi or to bacteria in general. A related dithiocarbamate product, Parzate, has shown beneficial selectivity in another way. This fungicide has been used to protect mushroom cultures from _Verticillium_ and _Trichoderma_ (Yoder et al 1951). Parzate (zineb) thus exhibited relatively low toxicity to a fungus group in which many mycorrhiza fungi of trees belong (_Agaricacae_).

An instance is reported (Hildebrand et al 1949) where good control of DO by Arasan in clay loam lasted for 45 days at least. Arasan controlled sugar-beet DO longer in dry than in wet soil (Hildebrand et al 1949). Some other studies (Tisdale et al 1945) failed to show any consistent correlation between soil properties and the control of DO by some chemicals. Strong's (1952) improved results by repeated applications of various soil fungicides suggests that the effects of these fungicides begin to decrease after one week. Since different fungicides vary so greatly chemically, they probably vary greatly in this respect also. Judging from the differences in control of pre- and post-emergence DO in Strong's tests (1952), Tersan, 5400, Manzate, and Ceresans remained effective longer than Bioquin I, Vancide 51, and captan.

The combination of seed treatment with soil treatment has given better control of DO than either alone. This has been tested at least for DO of grass (Beach 1953), some garden plants (Hildebrand et al 1949, McKeen 1950), and red pine (Riker et al 1947).

FOLIAGE TREATMENT BY PERSISTENT PESTICIDES

For most DO, ordinary foliage treatment usually is too late. If pesticides are applied to small seedlings, a portion of the chemicals reaches the soil and acts also as a soil fungicide. This may have been the case in the third application to pine DO by Strong (1952). Tersan, Manzate, Orthocide, and 5400 performed well in this way.

To complete the effect of soil sterilization by formaldehyde or chloropicrin, Cox (1953) has successfully applied monthly foliage sprays against blights of pine seedlings. The best chemicals were Bordeaux mixture, Manzate, zineb, ferbam, and thiram, all with added sticker. Phytophtora DO of Robinia has been successfully controlled by repeated sprays of Bordeaux mixture (Lambart and Crandall 1936). This is a type of DO which often begins at the top of seedlings, which may explain why the foliage treatment worked without soil treatments against DO.

It seems from the foregoing that those chemicals that are good for seed treatments, are usually good for soil and even foliage treatments. This has been substantiated under conditions allowing actual comparisons (e.g. McKeen 1950, Harrison 1953). In Strong's (1952) tests, captan, thiram, 5400 and Crag 658 gave a good or satisfactory control when applied in various ways. This is to be expected from these chemicals, which have good antifungal properties (Horsfall and Rich 1953), and which persist and adhere well but are low in phytotoxicity. Poorly adhering chemicals, as Vancide 51 which is water soluble, are exceptions. Ordinary seed treatment by Vancide 51 does not seem to be effective long enough to protect from postemergence DO, though the emergence is improved (Strong 1952).

SYSTEMIC FUNGICIDES AND CHEMOTHERAPEUTANTS

These affect DO from within the plant itself. They may be applied to the soil or directly to the plant. Vancide 51 (Hofman 1953) and perhaps nabam, zineb, thiram, and ferbam of the fungicides already mentioned may act partly in this way (Stoddard 1951, Haasis and Ellis 1950, Taylor 1953). It seems that a trend exists toward the development of fungicides of this group.

Chemotherapy of plants is quite a new field but is under intensive study. It has been found that even some such simple and not antifungal compounds, as ascorbic acid (Horsfall 1945), lime, and sugar (Hofman 1953) may cure a severely diseased plant. The compounds either change the metabolism of the plant and thus increase its resistance, or nullify the effects of pathogenic toxins (Horsfall 1945). The most comprehensive work on chemotherapy has been done both on diseases of large trees and on some soil-borne diseases of tomato, carnations, and egg-plant (Dimond et al 1949 and 1952, Hofman 1953 etc.).

One of the chemotherapeutants, 8-quinolenesulfate (chinosol) has controlled Rhizoctonia DO of some garden plants (Stoddard 1952, Stoddard and Zentmyer 1950). It was repeatedly applied to the soil (2 parts to 1,000 parts of soil) where it was proved to be taken up by the plants. A heavier doses (6 to 1,000) was injurious to peas. According to Carrera (1951) chinosol effectively inhibits the growth of Rhizoctonia solani, Pythium ultimum, and Fusarium avenaceum. Doran (1942) controlled Pythium DO of peas and some other plants by applying chinosol to the soil at 400 lbs. / acre. The related compound, 8-quinolenebenzoate (150 lbs. / acre) has given (Toole 1950) fairly good control to the Fusarium wilt of Mimosa.

DO and similar diseases have also been controlled by repeated soil applications of the chemotherapeutant, natriphene. This has performed well against Rhizoctonia diseases of several garden plants in repeated soil applications at 1:1,000 (Gould 1951, Ark 1951).

To mention only one more chemical of this group, sodium salt of 2-carboxymethyl mercaptobenzothiazole (HD109) has been amongst one of the best for Dutch elm disease as well as for Alternaria and Fusarium diseases of tomato (Dimond and Davis 1952). Dimond has recommended this against DO.

ANTIBIOTICS

Even in the narrow sense of the concept, antibiotics differ from the foregoing only in having often more specific subjects. Theoretically, some antibiotics inhibit DO organisms but still allow early formation of mycorrhizae or root nodules.

Unfortunately most antibiotics so far are relatively expensive and unstable in certain soils (Jefferys 1952). In recent tests by Gregory et al (1952 a and b), only actidione (partly also fradicin) showed promise for control of alfalfa DO, but was somewhat phytotoxic. In Strong's tests (1952), actidione gave considerable protection to red pine but only from pre-emergence DO. Actidione is strongly fungicidal to *Pythium* spp. and *Rhizoctonia solani* (Vaughn et al 1949, Klomparens and Vaughn 1952). Actidione (as well as captan) controlled leaf spot diseases of cherry (McClure and Cation 1951). It performed better than Bordeaux mixture.

Thiolutin is a new promising fungicide in this group (Gopalkrishan and Jump 1952). Infection of potato, lettuce and tomato by *Rhizoctonia* was greatly reduced by watering with solutions containing antibiotics (Hilborn 1953). The best ones were rimocidin, thiolutin, streptomycin and partly, magnamycin. *Verticillium* infection also was reduced by several antibiotics. To mention only one more amongst a number of antibiotics, ustilagic acid is very toxic to *Rhizoctonia solani* (Haskins and Thorn 1951).

NEMATICIDES

These, like antibiotics could be classified as logically into the preceding groups. Because the references above are concerned mostly with fungus control, particular attention to nematicides is needed. Recently very specialized chemicals have been produced against nemas. In Tarjan's (1953) tests against *Panagrellus redivivus*, the nematicides, Heptachlor 2E, Hyman 51-p-162, and Stauffer 244 were outstanding. These were not phytotoxic to tomato plants and had evident chemotherapeutic properties when applied to the soil at 400 lbs. / acre. N-244 was also one of the few effective, non-phytotoxic nematicides against white top of rice in the screening tests by Atkins and Todd (1952). Soil sterilization, of course, destroys nematodes. However, such compounds as formaldehyde and sulphuric acid are not very effective in this (Wilde 1936).

CONCLUSIONS

Cultural methods such as using proper number of good seed, stratifying seed, proper seed cover, maintaining reasonable nutritional level in soil, irrigation, and proper partial shading or additional lights in greenhouses provide a worthwhile degree of DO control, but seldom complete control.

Biological methods are not sufficiently developed to be applied in practice. The possibility of discovering effective and economical methods justifies further study.

Seed treatments by fungicides may give only uncertain protection. On the other hand, since they are inexpensive, they may be recommended for practical purposes, at least with methyl cellulose sticker (pelleting), where DO is mainly caused by ordinary DO fungi.

If seed treatment proves to be insufficient, especially for the desired complete control in breeding and other research work, repeated soil and foliage treatments by chemicals should be tried, both alone and in combination with seed treatments. New promising chemicals, especially those with therapeutic and antibiotic properties, need to be screened for phytotoxicity and effectiveness against DO. Of the new fungicides, a few have already been tried extensively and have shown generally good performance in various ways; these are thiram and possibly captan, 54, Manzate, chinosol, and Vancide 51. Some of these should be included in trials.

Where DO is caused by nematodes or by unusual organisms, some of the nematicides mentioned or complete soil sterilization by fumigants should be tried.

The mode of action of pesticides to DO and the factors which influence their performance are poorly understood, especially in soil applications. Therefore, even the widely accepted materials need to be tested to any particular location and in varying weather conditions.

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LIST OF ANTIPEST CHEMICALS

AND

THEIR MANUFACTURERS

NAME	ACTIVE CHEMICALS	MANUFACTURER
Actidione	Cyclo-heximide	Gallowhur Chem.
Agrox	Phenyl mercury urea	Chipman Chem. Co.
Arasan	see Thiram	E.T. duPont Co.
Anticarie	Benzenehexachloride	H.P. Rossiger
B H C	Benzenehexachloride	
Bioquin	Copper 8-quinolinolate	Monsanto Chem. Co.
Brassicol	Pentachloronitrobenzene	
Captan	N-trichloro methylthio tetra-hydrothalmide	Mallincraft Chem.
Calomel	Subchloride of mercury	
Ceresan M	Ethyl mercury p-toluene sulfonanilide	E.T. duPont Co.
N.I. Ceresan	Ethyl mercury phosphate	E.T. duPont Co.
Chinosol	8-Quinolene sulfate	Mallincraft Chem.
Chloranil	Tetrachloro parabenzoquinone	
Crag 658	Copper zinc chromate	Carbide & Carbon
Crag 974	3,5-Dimethyltetrahydro-1,3,5,2-thiadiazine-2-thione	Carbide & Carbon
Cryptonol	see Chinosol	
Dithane D-14	see Nabam	Rohm & Haas Co.
Dithane Z-78	see Zineb	Rohm & Haas Co.
Dow 9B	Zinc trichlorophenate	Dow Chem. Co.
Dowicide G	Sodium pentachlorophenate	Dow Chem. Co.
Ferbam Fermate	Ferric dimethyl dithiocarbamate	E.T. duPont Co.
Folosan	Tetrachloronitrobenzene	Bayer Agric. Ltd.
Fradicin	Unknown	
HD 109	2-carboxymethyl mercaptobenzo-thiazole	
Heptachlor 2E	1,4,5,6,7,8,8-Heptachloro-3a,4,7,7,7a-tetrahydro-4,7 methanoindene	
KF 467	Ethyl mercuric perthio-cyanate	
Magnamycin	A monobasic organic compound	
Manzate	Manganese ethylene bisdithio-carbamate	E.T. duPont Co.
Mycotox I	2,4,5-Trichlorophenyl acetate	Dow Chem. Co.
Nabam	Disodium ethylene bisdithio-carbamate	
Natriphene	Sodium 8-hydroxydiphenyl	Natriphene Co.

LIST OF ANTIPEST CHEMICALS

AND

THEIR MANUFACTURERS

(continuation)

NAME	ACTIVE CHEMICALS	MANUFACTURER
NP-1083	24-Dinitrofluorobenzene	Penn Salt
N-244	3-p-Chlorophenol-5-methyl rhodanine	Stauffer Chem.
Orthocide	see Captan	Stauffer Chem.
Paracide	p-Dichlorobenzene	
Parzate	see Zineb	Rohm & Haas Co.
PCNB	Pentachloronitrobenzene	Mathieson Chem.
Perenox	Cuprous oxide	Plant Products
Phygon	2-3 Dichloro naphtoquinone	U.S.Rubber Co.
Polymixin	Unknown	
Pomarsol	see Thiram	
Puraturf 177	Phenyl amino cadmium dilactate	Gallowhur Chem.
Rimocidin	A sulphate containing complex compound.	
Semesan	Mercury chlorophenol	E.T. duPont Co.
S. Bel	Hydroxymercurynitrophenol and hydroxymercurychlorophenol	
Spergon	see Chloranil	U.S. Rubber Co.
Streptomycin	N-methyl-L-glucoximinido-streptisidostreptidine	
Tersan	see Thiram (wettable)	E.T. duPont
Thiram	Tetramethyl thiuram disulfide.	
Tritisan	Pentachloronitrobenzene	Plant Products
Thiolutin	Unknown	
Ustilagic acid	An acidic glycolipid	
Vancide 51	Sodium dimethyl dithiocarbamate +sodium 2-mercaptobenzothiozate	R.J.Vanderbilt
Zineb	Zinc ethylene bisdithio-carbamate	
51-P-162	Hexachloro-cyclopentadiene	Hyman
275-D	Pentachloronitrobenzene	Mathieson Chem.
1182	4-Chloro-3:5-dimethylphenoxy ethanol	Carbide & Carbon
5400	Reaction product of dimethyl-dithiocarbamate and sulphur dichloride	Carbide & Carbon